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In-plane shear reinforcement of wood beam floors with FRP

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Abstract

A study of the behavior under shear of existing wooden floors reinforced with different materials and techniques has been carried out. The purpose of this study was to perform an experimental and numerical analysis of the shear properties of existing and reinforced wood beam floors. The wooden floors were reinforced using composite materials, reinforced concrete flat plate and wood planks. The experimental results show a significant increase in shear strength and stiffness of reinforced floors compared to those unreinforced. Numerical applications regarding the shear behavior of un-reinforced and reinforced wood floor are also presented. The comparison between the experimentally and theoretically determined shear stiffness also provided useful information for practical applications.

Keywords: B. Elasticity; C. Numerical analysis; D. Mechanical testing; Reinforcement

1. Introduction

Composite materials have been widely utilized in the field of civil engineering, both in new constructions as well as in the reinforcement of existing reinforced concrete structures. In the last few years the use of these materials has resolved some of the problems of historical structures, particularly regarding those in masonry. In fact it is common knowledge that masonry structures present severe structural weaknesses correlated to their lack of tensile strength.

Composite materials are well-suited to resolve problems, such as the stiffening of traditional floors, due to their poor mechanical characteristics. One of these regards stiffening in the plane of traditional floors. While intervening to reinforce or to effect seismic upgrading in historical constructions, works must often be carried out on traditional floors to increase their capacity to withstand stresses induced by vertical loads (perpendicular to the floor) as well as to obtain stiffening with regard to stresses in the plane caused by seismic actions and an improved distribution of the seismic action. In the past most of studies focused on the flexural reinforcement of wood/glulam beams with FRP materials (Fiber Reinforced Polymers) and on the adhesion properties [1–3]. It was recognized that FRP composite materials were characterized by very high adhesion stresses when bonded to wood [4–6] with epoxy resins.

When a reinforcement work is projected there are many critical issues including ensuring a durable bond between the FRP and wood given the shrinkage and swelling of wood due to moisture changes. The feasibility of using FRPs in civil engineering applications is strongly linked to the capability of these materials to maintain their mechanical and chemical properties during service. In this context, Loos et al. [7] carried out studies on the effect of aqueous solutions on the mechanical and chemical properties of glass/polyester composites. Measurements of various properties of FRP materials exposed to aqueous media showed the possibility of a sudden decrease, after a certain induction period, of the mechanical properties of composite materials upon exposure [8]. Glass fibers are economically competitive and are characterized by high mechanical characteristics. However glass transition temperatures for epoxy resins are generally not elevated and equal to 50–80 °C. Recently Tascioglu et al. [9] found that E-glass fiber/phenolic resin matrix pultruded composite materials designed for wood reinforcement are susceptible to fungal penetration by common wood decay fungi highlighting the risk of strength decrease and moisture increase. However in the case of reinforcement of wood beam floors, it must be pointed out that tensile stresses produced by seismic action are generally much lower than

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FRP tensile strength and many protective products may be used to ensure long-term durability.

Among the reinforcing techniques of wood beam floors most widely used in this field is that involving the application of a thin concrete slab, executed in the case of geometrically variable floors due to the ease of application of the conglomerate as well as to its adaptability to the needs of the work site [10]. However, the effectiveness of this type of intervention depends on the actual possibility of adhering the concrete slab solidly to the wood structure. In the absence of this condition the intervention can turn out to be ineffective, resulting only in an increase in the dead loads. Moreover, this type of reinforcement can result in an increase in the building's seismic vulnerability, particularly if the floor rests on traditional stone masonry-work, characterized by poor mechanical characteristics (double/triple-leaf roughly cut stone masonry walls).

Another technique involves reinforcing floors with steel plates, but this is applicable practically only in the case of simple geometries; furthermore, the problems connected to the increase in weight, as well as the expense involved, present real limitations to the use of this type of intervention [11,12].

Recently other techniques involving the application of multi-layered wood panels for structural uses have been proposed for existing wood floors [13]. This technique offers both elevated characteristics of reversibility and limited additional weight as well as a guarantee that the reinforcing application does not involve any significant damage to the existing wood structure.

This paper presents a study of a new technique of stiffening previously existing wood planked and solid brick floors utilizing the application of fibers in composite materials. The experimentation was carried out on unreinforced and reinforced floors, using traditional techniques, such as reinforced concrete slabs and layers of crossed planks, and new techniques with sheets of glass fibers. The aim was to study and accomplish aseismic protective system for floors. An analysis of the test results has furnished the criteria for the choice of interventions for seismic upgrading.

2. Typology of floors tested

The floors tested are of the mono-directional type with a chestnut-wood structure composed of a primary structure (beams) and a secondary structure (rafters). The floors are composed with one of two different techniques: with wood planks nailed to the underlying rafters or with a layer of solid bricks resting on the rafters. These two typologies of floors are widespread in Italian and European historical building and therefore are often the object of seismic upgrading.

The experimentation was carried out on samples of floors 3×3 m, made up of elements in real size, constructed expressly in the RITAM laboratory of the Terni branch of the University of Perugia (Italy).

The characteristics of the floor typologies are described in detail below.

2.1. Wood beam floor with overlying planks (plank floor)

The most classic typology is composed of beams, rafters and planks; numerous variants exist, above all regarding the arrangement and form of the planks and rafters. The distance of the rafters, the thickness and the finger joint of the planks and the way the various elements are connected, these characteristics assume a particular importance in the evaluation of the distribution capacity of the in-plane seismic actions of the floor. The laboratory tests were effected on samples of floors in chestnut-wood having a primary structure made of three beams $3100\times180\times180$ mm placed at a distance of 1100 mm. Wood rafters, $1100\times80\times80$ mm, were positioned above the beams. The planking consisted of wood elements 600 mm long with a cross-section as indicated in Fig. 1.

These elements were connected to the rafters with nails in various ways, using one or more nails for each end of the plank. The differing configurations in the rafter-to-plank connection caused two different constraint conditions which notably influence the behavior. The first configuration is a mechanism (one nail at each end) since the result is a system of closed links each composed of two tables and two rafters joined to each other by means of four hinges made of nails.

In this case, the resistance to a shear stress acting in the plane of the floor is determined only by the friction between the planks and the rafters and by the need to maintain the congruency without wood lacerations or penetration between planks. In the other configurations the number of constraints increases and a hyperstatic system results in which angular strain is prevented by the presence of nails positioned on the two short sides of each plank.

2.2. Wood beam floor with overlying solid bricks (solid brick floor)

This typology, widespread in the Mediterranean area and in Italy, was constructed in the laboratory, placing solid bricks (dimensions of brick: $140\times280\times30$ mm) on the secondary wooden structure consisting of rafters of a cross-section of 80×80 mm with a distance of 300 mm (Figs. 2 and 3). A layer of sand about 10 mm thick was placed above

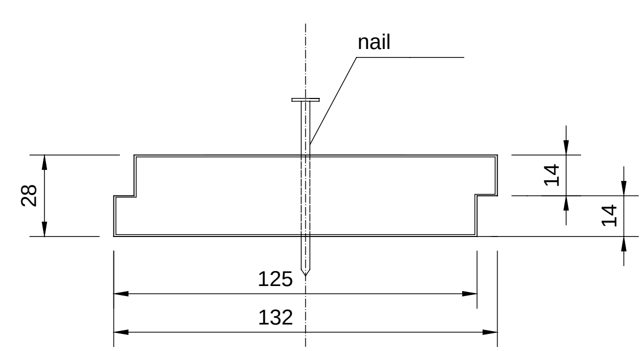
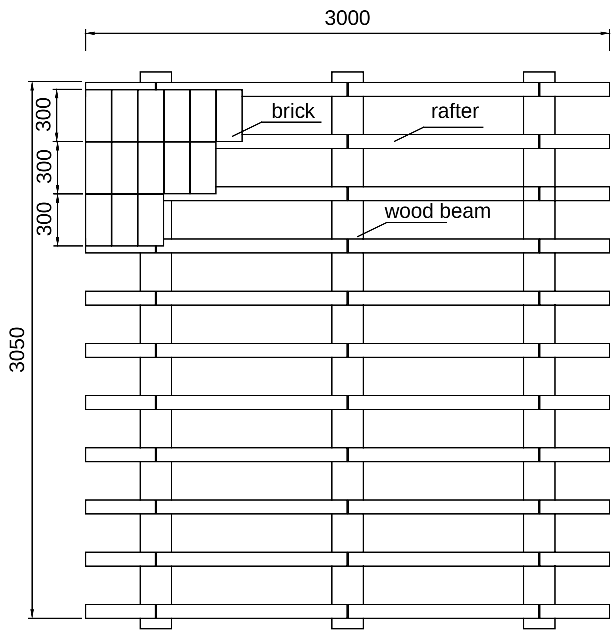


Fig. 1. Cross section of wood plank (dimensions in mm).



Figs. 2 and 3. Wooden beam floor with solid bricks.

the bricks to prevent phenomena of instability and to simulate the presence of a pier of a mortar with weak mechanical properties. The spaces between the bricks (maximum thickness of 3–4 mm) were filled with mortar.

3. Typologies of the applied reinforcements

In the experimentation the reinforcements capable of increasing stiffening and the strength of the floors were examined; in particular an analysis was carried out both of those traditional strengthening techniques which have widely been used in consolidation work on floors as well as of those innovative techniques which use materials only recently introduced in residential construction, such as FRP materials. In the first case the application of wood planks and concrete slabs was examined, while in the second case examination regarded the application of GFRP (Glass Fiber Reinforced Polymers) sheets.

3.1. Traditional reinforcing techniques

3.1.1. Application of an additional layer of planks

This method of reinforcement was utilized on floors composed of beams, rafters and wooden planking (plank floor) applying a second layer of planks of the same wood and geometry as the underlying layer, at an angle of 90° to the original flooring (Figs. 4 and 5). The rafters and the first planking are joined by means of four nails per plank, i.e. two at each end; the original and reinforcing plankings are joined by means of six nails, i.e. two at each end and two in the middle. The number of nails is particularly important since reinforcement is achieved due to the connection that the nails determine between the two layers of planks. Therefore, in order to avoid excessive tensile concentrations in the area of the nails which could determine a compression plasticization of the wood and in consequence a slotting of the nail holes, it is necessary to provide a sufficiently wide-spaced joining between the two layers of planks. Experimentation indicates that in order to avoid such a problem it is necessary to plan on using at least six nails per plank (two at each end and two in the middle).

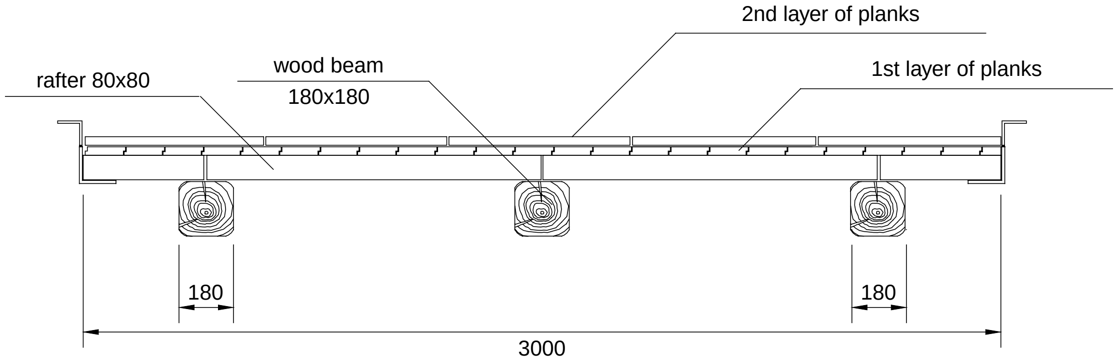
3.1.2. Reinforced concrete slab

Reinforcement using a lightened reinforced concrete slab 40 mm thick was carried out on a solid brick floor. The slab reinforcement is composed of an electro-welded steel bar mesh of a diameter of 6 mm (mesh 10×10 cm). The lightening of the concrete was obtained through the use of expanded clay, which determined a specific weight of 16.0 kN/m^3 for the conglomerate. The connection between the wood rafters and the concrete slab was obtained through the use of L shaped elements made of Fe B 44 k steel bars (diameter 8 mm) with 120 and 30 mm edges inserted in the slab and wood rafters to a depth of approximately 50 mm.

3.2. Innovative reinforcing techniques

The application of a composite material, utilized for both wood plank and solid brick floors, is justified by the fact that shear strengthening of floors presupposes an increase in the tensile strength in order to allow a better distribution of the forces.

In the case of the plank floor, a system of 100 mm wide sheets with unidirectional glass fibers glued to a plank using a bicomponent epoxy resin was applied according to two different schemes. In both cases, a second layer of wood planks, having the characteristics previously described, was applied above the still unhardened composite sheets at a angle of 90° with respect to the underlying plank layer and joined to this by means of six nails per plank (two in the middle and two at each end of every plank). The schemes of application of the GFRP sheets are shown in Figs. 6 and 7: the first pattern foresees a mesh of 300 mm with the sheets oriented along the diagonals, while in the second the fiber sheets are applied along the perimeter of the floor surface and along the two diagonals. Glass fibers are



Figs. 4 and 5. A traditional reinforcement: application of an additional layer of planks.

characterized by a Young modulus of 71 GPa, tensile strength 2900 MPa, superficial density 0.320 kg m^{-2}, equivalent width 0.114 mm.

In the case of the solid brick floor the reinforcement with glass fibers, having the same mechanical characteristics as those used for the planked floor, was applied following the pattern in Fig. 6. A 10–15 mm layer of hydraulic lime characterized by a compression strength of 2.4 MPa was applied to protect the glass fibers and prevent eventual phenomena of instability.

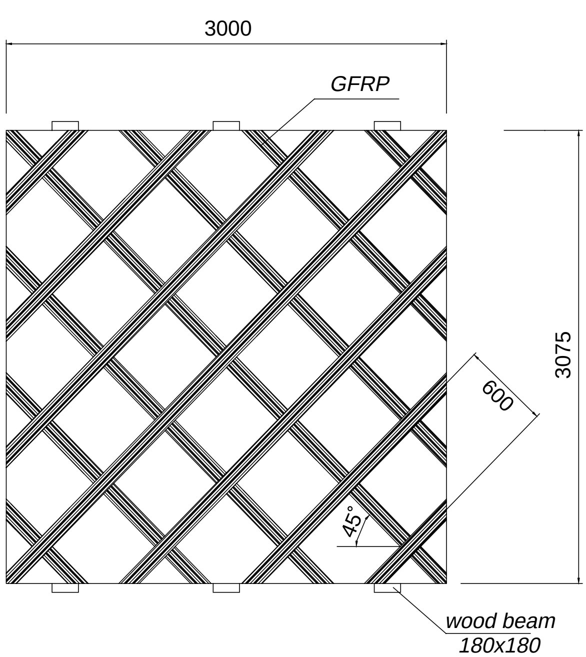


Fig. 6. GFRP reinforcement for floor no. 5.

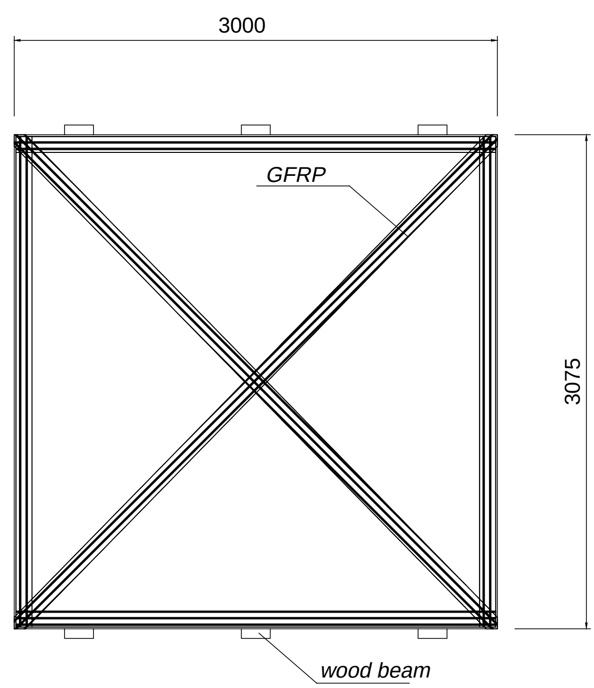


Fig. 7. GFRP reinforcement for floor no. 6.

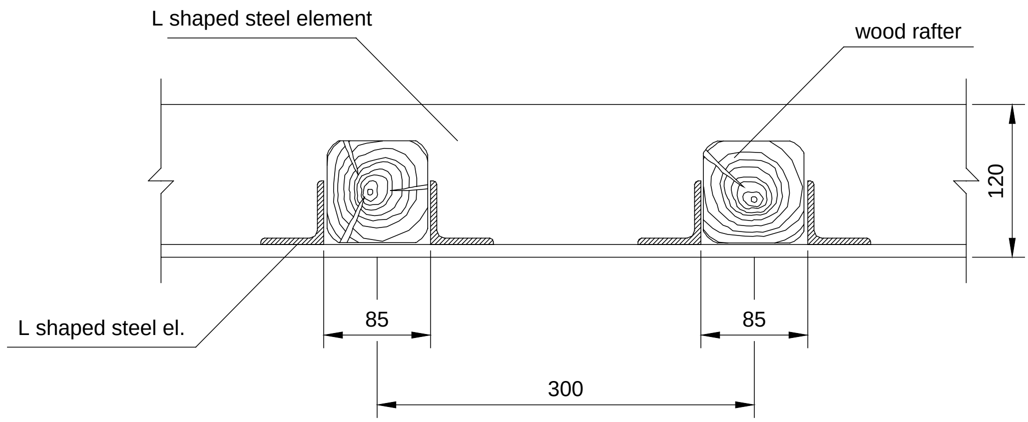


Fig. 8. Rafter anchorage to steel frame (dimensions in mm).

4. Experimental

The above-described floor samples were constructed in the laboratory using elements in real size (beams, planks, bricks). Each floor was anchored to a perimetral steel structure made of L-shaped steel profiles (120×120×10 mm) connected to one another by means of four cylindrical hinges. The rafters were anchored by means of the arrangement of L-shaped steel elements as shown in Fig. 8.

The system made up of the perimetral frame and the floor was rested on the pavement on wheels which permit the movement of the floor in its plane without setting in motion significant values of friction. This system was carefully laid on the wood beams, which were in turn resting on the pavement by means of devices designed to limit friction. In the horizontal plane, the frame was constrained using metal anchorages connected to the laboratory walls and floor. The load system was composed of a hydraulic jack placed so that it applied a force acting on the steel structure in the plane of the floor in two different directions: parallel and perpendicular to the wood beams.

Three inductive traducers (LVDTs) were applied to each floor sample: two laid along the two diagonals and the third in the direction of the applied shear force (Fig. 9). Each test was carried out using load–unload cycles with increments of 3 kN for each cycle until failure of the floor. The movements in correspondence to the three inductive transducers and the hydraulic jack pressure were acquired as a function of time during the test.

A description of the behavior of the floor in the plane was supplied by the function which relates the shear force applied and the resulting movement:

$$F = kx \cong k(\gamma d) \tag{1}$$

in which k is the shear stiffness of the floor, γ the angular strain and d is the length of the edge of the floor perpendicular to the direction of the applied shear force.

It was possible to evaluate the shear stiffness k for all loading cycles and in particular k was calculated (the secant value at 1/3 of the maximum load) on the envelope curve of the loading cycles.

$$k_{1/3} = \frac{F_{1/3} - F_i}{\gamma_{1/3} d} \tag{2}$$

The angular strain, γ, was calculated by referring to the strains ε_c and ε_t, measured in correspondence to the diagonals, respectively in compression and in traction:

$$\gamma = \varepsilon_c + |\varepsilon_t| \tag{3}$$

$$\varepsilon_c = \frac{\Delta d_c}{d_c} \qquad \varepsilon_t = \frac{\Delta d_t}{d_t} \tag{4}$$

In summary, the experimentation was effected on ten floors, four of which were unreinforced and six reinforced, listed in detail in Table 1. For further clarity each test is indicated by a combination of three indices: the first identifies the progressive number of the test, the second identifies the type of floor [T2 = planks nailed to rafters using two nails per plank; T4 = planks nailed to rafters using four

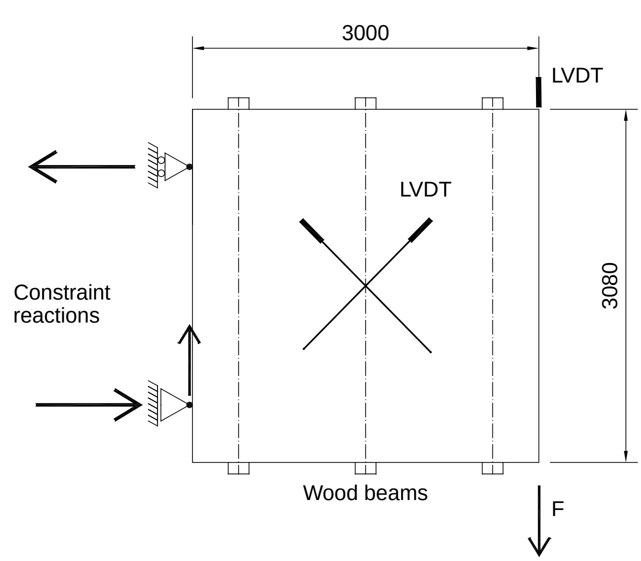


Fig. 9. Test static scheme with indication of position of wood beams and LVDTs (dimensions in mm).

Table 1
Wooden beam floors tested

Test no.	Wood beam floor type	Reinforcement type
01-T2-OR	Layer of planks (two nails: one nails at each end)	None
02-T6-OR	Layer of planks (six nails: three nails at each end)	None
09-T2-OR[a]	Layer of planks (two nails: one nails at each end)	None
03-T4-T6	Layer of planks (four nails: two nails at each end)	Additional layer of planks (six nails: two at each end and two in the middle)
05-T4-FV	Layer of planks (four nails: two nails at each end)	Additional layer of planks, GFRP mesh of 600 mm (six nails: two at each end and two in the middle)
06-T4-FV	Layer of planks (four nails: two nails at each end)	Additional layer of planks, GFRP applied along diagonals and perimeter (six nails: two at each end and two in the middle)
10-T4-FV[a]	Layer of planks (four nails: two nails at each end)	Additional layer of planks, GFRP mesh of 600 mm (six nails: two at each end and two in the middle)
07-PI-OR	Solid bricks	None
08-PI-FV	Solid bricks	GFRP mesh of 600 mm and layer of hydraulic lime
04-PI-CL	Solid bricks	RC slab

[a] Load orthogonal to wood beam axis.

nails per plank; T6 = planks nailed using six nails per plank (three at each end); PI = solid brick] while the third index indicates the type of reinforcement [OR = unreinforced floor; T6 = plank floor nailed perpendicularly to the underlying floor with six nails per plank; CL = reinforced concrete slab; FV = GFRP sheets and overlying wood plank floor].

5. Experimental results

The results of the experimentation, partially anticipated in [14], are reported in Table 2 and represented graphically in Fig. 10.

The values measured for the tests on the unreinforced floors can be considered as the minimum values of strength and stiffness, since these floors are a mechanism and their shear strength and stiffness are essentially determined by phenomena of friction between the elements making up the floor. They are therefore taken as reference values to evaluate the improvements in reinforcing techniques.

5.1. Plank floors

Of the seven tests carried out on plank floors, the three tests identified by the indexes 01-T2-OR, 02-T6-OR and 09-T2-OR have been executed on un-reinforced plank floors in order to find their mechanical properties and to compare these values (shear stiffness and strength) with the ones of reinforced floors.

The first test effected on the un-reinforced wood floor with an overlying plank floor nailed to the rafters by means of two nails per plank (01-T2-OR) resulted in values of shear stiffness and strength respectively equal to 0.47 kN mm^{-1} and 4,940 N (Fig. 10). Increasing the degree of constraint between the rafters and the plank floor by means of six nails for each plank (02-T6-OR) causes an increase in the shear strength, but does not increase shear stiffness much: the reinforcing work is quite useless insofar as producing an increase in stiffness. A decrease in the shear stiffness may also be imputed to the application of the six nails per plank to a floor having two nails per plank and previously subjected to testing, during which slotting was verified in the first two holes. This in turn caused a decrease in shear stiffness (k = 0.28 kN mm^{-1}) in the successive test (02-T6-OR).

With regard to traditional reinforcing techniques, the test carried out on a new floor (03-T4-T6) composed of a wood plank floor nailed to rafters using four nails per plank, reinforced by means of an additional and similar plank floor placed on top of the preceding one at an angle of 90° and joined to it using six nails, resulted in only a slight increase in both stiffness and strength, which reached the values of 1.71 kN mm^{-1} and 19,310 N, respectively. The additional layer of plank is not able to cause a significative increase in shear stiffness because plasticization in compression of the wood occurs as consequence a slotting of the nail holes. This reinforcing technique could be effective only if high-strength woods are used both for floors and reinforcing.

Test no. 5 (05-T4-FV), a floor with wood planks reinforced with GFRP, resulted in a stiffness of 11.2 kN mm^{-1}. The reinforcement using unidirectional GFRP sheets, inserted between two layers of wood planks, is able to significantly increase the strength of the floors, greatly improving the increase in stiffness compared to the double plank floor without reinforcement (test 03-T4-T6). In any case, the experimental tests evidenced the fact that it is necessary to use a mesh with the GFRP sheets placed at a not

Table 2
Results of shear tests

Test no.	Max load (N)	$k_{1/3}$ (kN mm^{-1})	$\gamma_{1/3}\times 10^{-3}$
01-T2-OR	4,940	0.47	0.46
02-T6-OR	12,380	0.28	4.87
03-T4-T6	19,310	1.71	1.01
04-PI-CL	42,370	169	0.02
05-T4-FV	65,630	11.2	0.56
06-T4-FV	57,840	5.04	1.28
07-PI-OR	5,010	0.28	0.50
08-PI-FV	59,754	99.3	0.04
09-T2-OR[a]	4,770	1.05	0.40
10-T4-FV[a]	64,180	22.8	0.24

[a] Load orthogonal to wood beam axis.

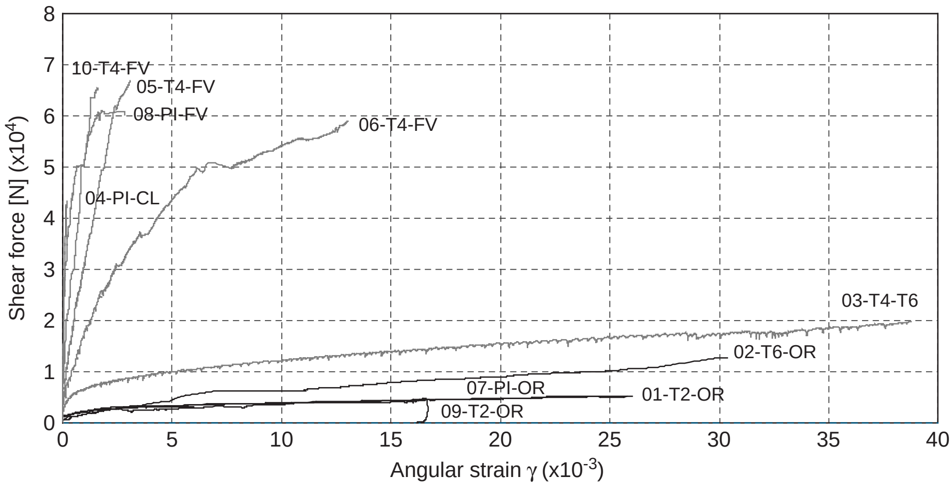


Fig. 10. Shear force vs angular strain.

very elevated distance in order to obtain an interesting increase in the stiffness: interesting results have been obtained for a distance of 600 mm.

Of particular significance is the experimental result obtained from the test on a wood floor with overlying solid bricks, reinforced with GFRP and a thin layer of hydraulic mortar. The test results indicated an elevated stiffening equal to 99.3 kN mm^{-1} and a strength (maximum load) of 59,754 N. The presence of the fibers and of a thin layer of hydraulic mortar as well as the gluing of the fibers themselves onto the solid bricks (which is therefore included in the resistant mechanism of the floor) determine an elevated increase in stiffness, similar to that obtained for the floor strengthened using a reinforced concrete slab.

In the last two tests (09-T2-OR and 10-T4-FV) the shear force was applied perpendicularly to the wood beams. No significant variations in strength were observed compared to the case in which the force was applied parallel to the beams. On the contrary, different results were found with respect to the stiffening strength: the unreinforced floor resulted more rigid (1.05 kN mm^{-1}) than the same floor with a force parallel to the wood beams (0.47 kN mm^{-1}); the results are inverted if the floors reinforced with unidirectional glass fiber sheets are compared.

5.2. *Solid brick floors*

Three solid brick floors were tested with the same test apparatus used for plank floors. The test carried out on floor n. seven without reinforcement (07-PI-OR) resulted in very low shear strength and stiffness ($F=5{,}010$ N, $k=0.28$ kN mm^{-1}); the configuration of this type of floor is a mechanism as bricks are only placed over rafters without any mechanical fixation. Shear strength is determined only by friction.

On the contrary, the floor (04-PI-CL) reinforced using a lightened reinforced concrete slab 4 cm thick determined very elevated shear stiffness equal to $k=169$ kN mm^{-1}, confirming that the intervention renders the floor extremely stiff. The last floor was reinforced with composite materials (08-PI-FV) and a thin hydraulic lime slab 10–15 mm thick. The composite material (GFRP) caused a very high increase in floor tensile strength while the hydraulic lime contributed to prevent instability phenomena, increase compression strength and friction between solid bricks. As matter of fact the maximum shear load measured was equal to 59,724 N and the shear stiffness 99.3 kN mm^{-1}. The shear stiffness of this floor is similar to the one measured for the floor reinforced with a concrete slab ($k=169$ kN mm^{-1}) whose corresponding value may be considered the upper bound.

6. Numerical analysis

On the basis of the experimental results, for the purpose of carrying out a series of numerical simulations designed to evaluate the stiffness k of the floors, a finite element numerical modeling was done for the wood structure with wood plank or solid brick floors. The finite element modeling was done using the calculation code Sap 2000, ver. 7.4.2.

Beam elements with 2 nodes were used for the wood beams, the rafters, the composite material fibers and the steel framework, while 4 node *shell* elements were used to model the solid brick floor (shell dimensions: 140×280×30 mm), the wood plank floor (shell dimensions: 121×600×28 mm) and the reinforced concrete slab (shell dimensions: 75×75×40 mm) (Fig. 11).

The wood was modeled for orthotropic behavior (perpendicular to the grain: radial and tangential principal material directions; parallel to the grain: axial material direction) with mechanical characteristics based on the results obtained from monoaxial compression tests in the laboratory and/or from data and correlations found in the bibliography (Young elasticity modules E_a, E_t, E_r equal, respectively, to 9000, 820 and 450 MPa; shear modules G_{at}, G_{tr}, G_{ra} equal, respectively, to 160, 290 and 3210 MPa and Poisson coefficients ν_{at}, ν_{tr}, ν_{ra} equal, respectively, to 0.30, 0.37 and 0.47); steel (isotropic, $E=200$ GPa, $\nu=0.30$) and the composite material (in direction of the fibers, $E=17.5$ GPa) were modeled as linear

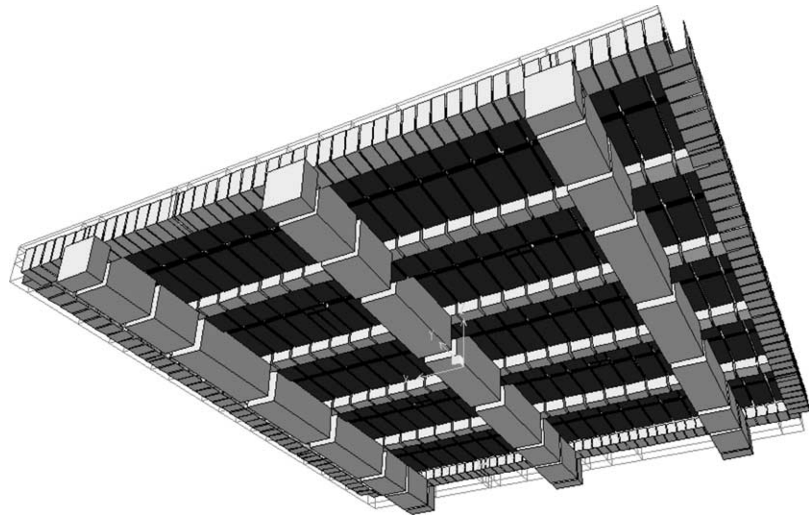


Fig. 11. Wooden beam floor finite element model.

elastic materials. Finally, values of E and ν equal, respectively, to 21,090 MPa and 0.20 were assumed for the reinforced concrete, considered as a isotropic material and in the case of short term loads acting on concrete without any cracks.

Three types of floors were modeled: a plank un-reinforced floor, a wood floor with solid bricks reinforced with a concrete slab, and a plank floor reinforced with GFRP materials.

The plank-to-rafter nailed connections for the plain plank floor were modeled with three frame elements (two horizontal and one vertical). The flexural stiffness of two horizontal frame elements is sufficient to prevent relative movements between shell elements connected. In order to simulate the nail presence each vertical frame element was divided in two vertical elements and torsion moment was placed equal to zero (Fig. 12).

With regard to plank-to-plank interaction, the elements making up the single plank, two plank floors, independently of the pattern of reinforcing (with GFRP) adopted, are connected by means of *gap* elements. The gap elements are characterized by 6 springs, but only the one that is able to prevent the in-plane mechanism is activated. The spring stiffness value is determined using the results obtained from the laboratory experimentation for a 28 mm plank thickness. Once the spring stiffness was fixed, it was possible to note that a change in wood elastic properties or plank dimension or nailed connections may cause little variations in floor stiffness $k_{1/3}$.

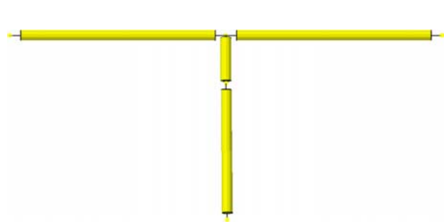


Fig. 12. Scheme of the F.E. model for a single nail.

In the case of floors with double wood plank floors (with or without GFRP sheets), new friction phenomena occur between wood layers and the spring stiffness previously estimated must be recalculated. The spring stiffness of the gap element was calibrated and correlated to the stiffness $k_{1/3}$ of the floor experimentally determined.

With regard to floors with GFRP reinforcement, even if a glued FRP-wood joint is not governed by friction, we assumed that by increasing moreover the spring stiffness of gap elements it is possible to take into account an increase in friction and therefore, similarly, the variation in the gluing surface between the planks and the GFRP. Considering that the gluing surfaces is linked to the GFRP sheet distance, in Fig. 13 the correlation between spring stiffness and GFRP sheet distance is shown. In this way it was possible to effect a parametric study which supplies some indications regarding the stiffness $k_{1/3}$ of these floors as the elasticity module of the GFRP, the distance of the fibers and their thickness are varied.

With regard to RC slab reinforcement, steel L-shaped elements connecting RC slab and bricks were modeled using frame elements. For this type of reinforcement, friction was not taken into account and it was assumed perfect adhesion between bricks and concrete. The Young modulus and Poisson coefficient values assumed for modeling the RC slab are valid for short-term loads acting and without any cracks.

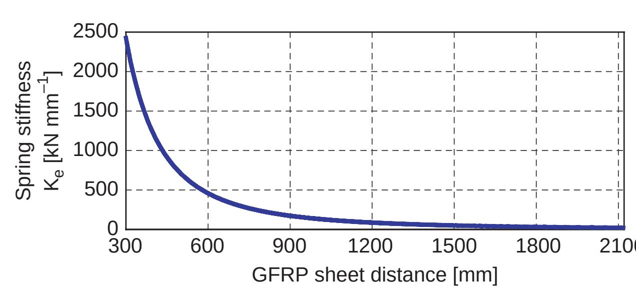


Fig. 13. Spring stiffness vs GFRP sheet distance.

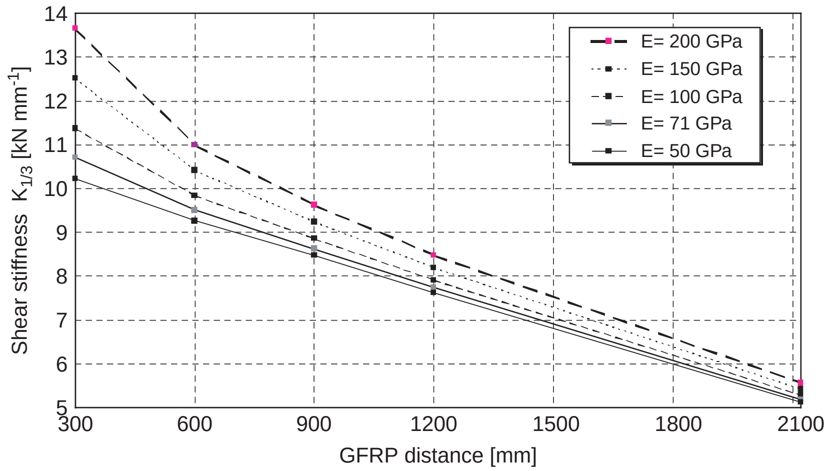


Fig. 14. FEM analysis: double layer of planks with GFRP sheet reinforcement.

A parametric analysis in the service state was finally carried out in order to find the shear stiffness values for different GFRP reinforcement works. Figs. 14 and 15 show the results of the modeling in order to determine the stiffness of the floor type with wood plank flooring reinforced with GFRP sheets according to variations in the distance of the fibers, their elasticity modulus and their quantity (thickness).

The results of the modeling showed that a single application (without glass fiber) of an epoxy resin between two layers of plank floors can significantly increase stiffness as showed in

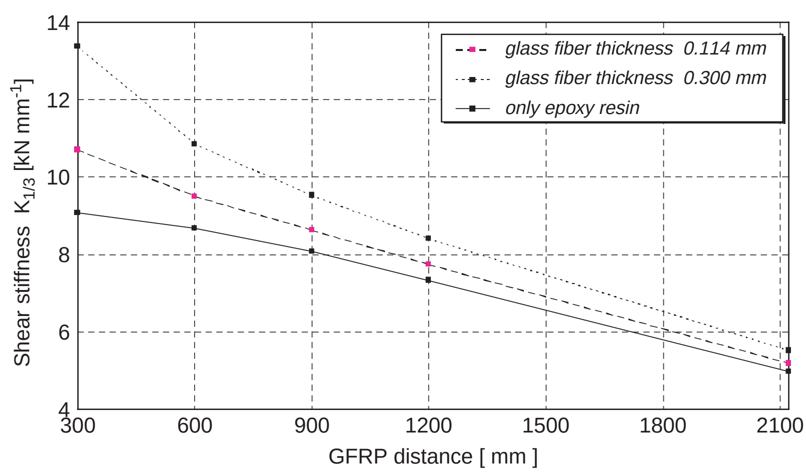


Fig. 15. FEM analysis: double layer of planks with GFRP sheet reinforcement: shear stiffness vs GFRP sheet distance.

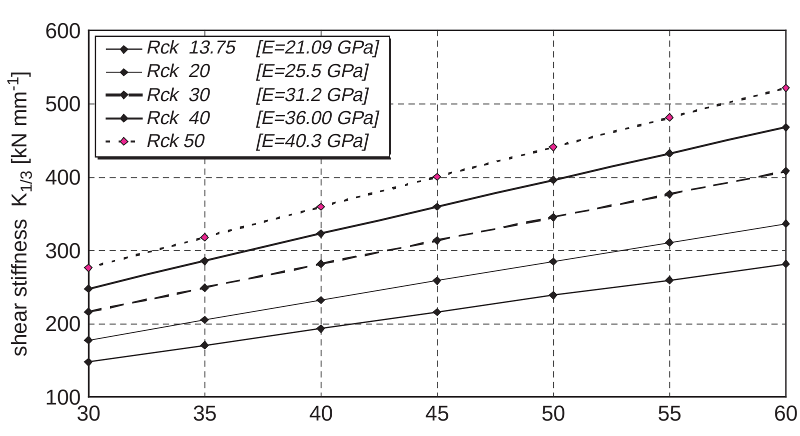


Fig. 16. FEM analysis: reinforcement with RC slab: shear stiffness vs slab thickness.

Fig. 15. However the application of the glass fibers with the epoxy resin may produce a further increase in the stiffness values up to 50% compared to the case in which epoxy resin is used without fibers. Moreover, it was observed that interesting values for stiffness were obtained in the case of GFRP meshes not exceeding 300–600 mm.

Finally, Fig. 16 shows a parametric study in which stiffness is presented as a function of the thickness of the reinforced concrete slab and of the normal elasticity module of the concrete itself.

7. Conclusions

Knowledge of the shear behavior of traditional floors before and after reinforcement constitutes an important element in designing interventions of seismic upgrading work of masonry-work buildings. In this paper some results obtained from a series of experimentations effected are presented.

Test results of two among the floor typologies most widely found in Italy and Europe (wood floors with planks and wood floors with solid clay bricks)—even though caution must be used in light of the limited statistical sample—clearly demonstrate an extremely low shear stiffness and strength.

A reinforcement in GFRP sheets was used to increase shear stiffness and strength of the floors, gluing the fibers to the upper surface of the planks or bricks. In the first case, another layer of planks was placed over the composite material sheets, while in the second case a slab in hydraulic lime mortar was applied. A significant increase in strength was obtained in both cases, even though the strength resulted greater in the case of reinforcement of solid brick flooring with GFRP sheets and with a thin layered slab in hydraulic mortar.

Among 'traditional' methods, the application of a slab in reinforced concrete was taken as the reference case in which maximum stiffening is attainable even though, in terms of maximum load applied, a smaller increase was measured compared to that resulting from reinforcement with wood planks and GFRP sheets.

In fact, reinforcement with GFRP sheets inserted in two layers of wood plank floors resulted in a significant increase in stiffening together with an elevated increase in strength. The tests carried out demonstrated the necessity of intervening with a rather close-knit composite mesh, uniformly distributed on the floor surface.

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